

New Technology Demonstration Program

FEMP

Federal Energy Management Program

*Trends in Energy Management
Technology – Part 4*

Review of Advanced Applications in Energy Management, Control, and Information Systems

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LBL – 53546

February 2004

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Federal Energy Management Program, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Introduction and Background

Introduction

In this article, the fourth in a series, we provide a review of advanced applications in Energy Management, Control, and Information Systems (EMCIS). The available features for these products are summarized and analyzed with regard to emerging trends in EMCIS and potential benefits to the Federal sector.

The first article [1] covered enabling technologies for emerging energy management systems. The second article [2] serves as a basic reference for building control system (BCS) networking fundamentals and includes an assessment of current approaches to open communications. The third article [3] evaluated several products that exemplify the current state of practice in EMCIS.

It is important for energy managers in the Federal sector to have a high level of knowledge and understanding of these complex energy management systems. This series of articles provides energy practitioners with some basic informational and educational tools to help make decisions relative to energy management systems design, specification, procurement, and energy savings potential.

Background

In this series of articles, the term EMCIS (energy management control and information system) has been used to refer to emerging EMS or EMCS with expanded information processing

capabilities beyond the traditional building control and energy management functions. These expanded capabilities include data exchange and archiving, historical data visualization, and energy data analysis [1].

Beyond the standard functions of EMCIS are advanced applications to help facility/energy managers operate and maintain their facilities in a manner that maximizes occupant comfort and energy efficiency, while minimizing costs. In most cases, the applications are stand-alone products that perform a specific function. Some are a component of an EMCIS while others integrate with and access data from an EMCIS.

Advanced Applications Categories

There are multitudes of application types for EMCIS. In this article, the focus is on categories that are emerging and considered state-of-practice. Some application categories are mature while others are so advanced that many of the applications within the category are still at the research level. However, only applications that actually have working prototypes and have been field-tested were reviewed in this article.

The advanced applications categories in this article are:

- Data Visualization Tools
- Portable User Interfaces
- Energy Analysis Tools
- Advanced Control Algorithms
- Fault Detection and Diagnosis Tools
- Occupant Interaction and Feedback Tools

In all, a total of thirty-nine applications were reviewed. There are many others that were not reviewed due to resource and time limitations.

Organization of the Report

The remainder of the report is organized into three major sections. The first section is a technology description of the different categories of advanced applications reviewed in this article. The second section discusses the potential of these applications; their benefits, limitations, and cost effectiveness. The report ends with a summary and conclusions section. There is also an appendix containing multiple tables that summarize some of the main features of each advanced application category.

Technology Description

This section describes the technology in each of the advanced application categories that were reviewed. However, a detailed features comparison for the applications product in each of the categories are provided as a series of tables in Appendix B¹.

Data Visualization Tools

With direct digital control devices, intelligent supervisory panels, and multi-tiered networking, EMCIS have the potential to collect and archive a tremendous amount of data. The availability of the data allows operators, facility managers, and energy managers to keep an eye on the health of the BCS

¹ With the exception of the Occupant Interaction and Feedback Tools category - no features comparison table is provided.

and to perform activities such as monitoring for abnormal conditions, verifying environmental comfort levels, and testing new strategies to save energy.

With large volumes of data, presentation of the data becomes an issue. Simple tabular data presentation may be sufficient for a small set of data. For a large set, it becomes difficult to identify trends, patterns, or irregularities. One option is to export the data to other software for analysis. For example, a spreadsheet program can easily be used to present exported data in a graphical form for visual analysis. However, the export process becomes tedious if data analysis is a routine day-to-day operational task, and the creation of such a spreadsheet requires considerable resources.

Data visualization software usually comes with standard tools such as graphical equipment monitoring and trend plots. The former displays real-time data on a graphical representation of the equipment. The latter are time-series graphs of the data contained in the trend logs.

More advanced data visualization tools improve on trend plots by trending either multiple data points on the same plot or multiple days of one data point on the same plot. Another variation on trend plotting is displaying separate trend plots for each of the days of the month on one screen. A third approach is to “stack” the daily trend plots onto a third axis. This creates a 3D surface profile plot where the 2D lines of each daily trend plot now forms a surface. Any valleys or peaks can be easily identified

as possible irregularities that may warrant further investigation.

Another advanced data visualization tool is XY scatter plot. This is a plot of data from two different physical points or variables. One point/variable is plotted on the x-axis and the other on the y-axis. A complete plot contains many dots (points on a graph); each represents the values of both points/variables at one moment in time. Directionality of clusters of dots indicates some sort of trend. Isolated dots indicate potential problems.

A new class of tools, called “performance” monitoring tools, is emerging from one vendor, Johnson Controls. These tools use “abstraction” and “metaphor” visualization techniques that can be used to help identify possible impending equipment faults. Johnson Controls has given names to these “performance” monitoring tools²; Analog Profile, Comfort Chart, Color Spectrum, River of Time, Starfield, and System Analysis Tool.

One of the performance monitoring tools uses the rate of change of the setpoint error to predict the future offset from the setpoint. This predictive feature is a type of fault detection and diagnosis (FDD) analysis. While a detailed description of the tools is given in the appendix, a detailed analysis of effectiveness of these tools is beyond the scope of this study.

² Details of these tools are provided in Appendix B.

Portable User Interfaces

The work environment of building operators and maintenance personnel has evolved in recent years. Building operators and maintenance personnel are constantly on the move, going from one service or maintenance area to another. Portable user interfaces are now available to these mobile personnel that provide access to system data when needed. This access was previously only available with stationary workstations or cumbersome laptops.

PocketControls from Abraxas Energy, and Sigma Compact Edition from Invensys Climate Controls (United Kingdom) are portable user interfaces implemented on Personal Digital Assistant (PDA) platforms running either Microsoft CE or PocketPC operating systems. Both products provide the basic features of a standard workstation such as view/acknowledge alarms, view point values, view and graph trend logs, and change setpoints.

The two products do differ in how they are used. The intent of the Invensys Sigma Compact Edition is to serve as a substitute for a standard workstation at equipment locations where no workstation is available. The Invensys product accesses the building control system either by Ethernet connection to the equipment bus or by direct serial or Ethernet connection to a nearby controller.

The PocketControl product, on the other hand, is intended to be a truly mobile device. Abraxas Energy provides the product as a turnkey system that includes a preconfigured server that interfaces to a building control system

workstation and serves the data to the PocketControl device over a cellular data service. The service provider is the choice of the end user.

Energy Analysis Tools

A major concern of today's facility manager is the operation of the facility not only in the most energy efficient manner, but also at the least cost. Both are difficult tasks, but the latter is the most difficult. With electric and natural gas deregulation, there are many more choices for energy suppliers and additional choices for long-term energy supply contracts. These contracts normally have peak demand charges or the state's public utility commission may mandate peak demand charges. To make sure the facility's energy budget stays in the black, the facility must be operated not only in the most energy efficient, but also most power-demand efficient manner.

Energy Analysis software is commonly available as an option from building controls vendors. In recent years, many products specifically tailored for energy analysis have been developed and deployed. All provide graphs and reports that are used to:

- Adjust operations and scheduling to help minimize energy use and lower peak demand.
- Negotiate energy contracts for more favorable terms.
- Benchmark against published statistical data to see if systems need optimization or upgrading.
- Cost allocate energy use.
- Validate utility bills.

Most of the energy analysis products reviewed in this study follow the current software development trend by utilizing a web interface. The advantages of a web interface were thoroughly discussed in the third article [3] of this series. A few of the other product vendors are also following the business model trend of being applications service providers (ASP). As an ASP, the vendor does not sell the software to the end user, but rather provides the software as a service. From the vendor's point of view, being an ASP potentially brings in a continuous and somewhat predictable source of revenue. From the end user's point of view, paying for the service reduces the risks of up-front capital expenditures for software and possibly hardware and recurring expenses for software operations and maintenance. This is especially true for small companies or for companies with limited budgets.

A few of the products offer comprehensive features that include:

- Energy analysis tools to benchmark energy usage by normalizing it with building parameters such as square footage and number of occupants and to compare energy usage between different buildings.
- Load management tools to monitor and optimize loads, and to manage strategies to shed loads and reduce peak demand.
- Billing analysis tools to do “what if” analysis by applying energy usage to different billing rates, to generate energy invoices for facility tenants, and to verify bills from the utility or energy provider.

- Forecasting tools to predict next day and next second-day energy usage for advance load shed strategy planning to avert peak demand charges.
- Reporting, real-time monitoring, alarming, and remote control tools.

Two emerging tools are tools for advanced data mining and distributed energy resource control. The advanced data mining tool utilizes Online Analytical Processing (OLAP) technology that can be used to interactively design custom reports that “slice, dice, and drill down” into large amounts of data. Distributed energy resource³ control tools are used to monitor and control distributed energy resources. Control can range from simple remote control on/off, to predefined schedules, to automatic triggering by events, to control by sophisticated algorithms.

Advanced Control Algorithms

Back in the days of pneumatic controls, control algorithms included proportional (P) and proportional plus integral (PI) control techniques implemented in fluidic controllers. With the advent of microprocessor-based controls and direct digital control, P and PI were implemented in software. With the power and flexibility of the microprocessor, proportional plus integral plus derivative was also implemented (PID). However, even much more powerful algorithms can be implemented.

³ This used to be called distributed generation, but distributed energy resource is a more general term that covers non-generation energy resources such as solar. .

One innovation is the introduction of adaptive logic to the control algorithm. Adaptive logic is used to continuously adjust the control parameters (proportional band, integral times, and deadband) to maximize the responsiveness of the system while maintaining stability. The adjustments are made based on values of measured data or recognizing certain patterns in the measured data.

Adaptive logic is also implemented in the controllers for variable speed drives used on chillers. The optimal speeds for variable-load and water-temperature combinations are learned and remembered to maximize energy savings.

At the research level, more advanced algorithms including finite state machine control sequencing and neural networks are being developed. Finite state machine logic defines specific states, or modes of operation under various conditions. Within each state, control directives are issued. A neural network is a software system that has highly interconnected tasks, working in parallel; like the human brain. Neural networks must be trained with data and expected output, and have the ability to learn. Neural networks can be used in highly nonlinear and dynamic processes where traditional control algorithms become overly complex.

Fault Detection and Diagnosis Tools

One of the important emerging EMCIS applications is software for fault detection and diagnosis (FDD). Many

buildings do not perform as expected because of problems and errors that occur during the stages of the building life cycle, from design, to commissioning, to operation. FDD tools have the potential to quickly diagnose operational problems with the building HVAC equipment and as a result, the equipment will operate as intended for a larger proportion of the total run time. The benefits of properly operating HVAC equipment include [4]:

- Improved occupant comfort and health
- Improved energy efficiency
- Longer equipment life
- Reduced maintenance costs
- Reduced unscheduled equipment down time

However, the impact of these benefits is difficult to quantify and is a barrier to widespread adoption of the diagnostic tools [4].

FDD tools are an emerging application for use in building commissioning and operation. Most tools are still in the research stage with functional prototypes. Many have undergone field trials and are being improved. Only a few of the tools are actually available commercially. However, none of the tools are components of current BCS/EMCIS offerings; i.e., all are standalone applications. Some operate in batch mode, taking data input from files. Others take data input online, either directly from the BCS/EMCIS or from a data gateway.

FDD tools employ either a top-down or a bottom-up approach. In a top-down approach, high-level performance

measurements (such as whole building energy use) are used to detect possible problems in the lower level hierarchy of the BCS. The other, bottom-up approach, uses low-level performance measures to isolate the exact equipment fault and then propagate the problem up to higher levels to determine what the impact is on the whole building.

By its very name, FDD tools perform fault detection and fault diagnosis. The two are different operations. Fault detection is the determination that the building or equipment operation is incorrect or not within expected performance levels. Faults may occur over the whole operating range or be confined to a limited region and hence only occur at certain times. After a fault is detected, fault diagnosis is the identification of the cause of the fault as well as the location (which equipment) of the fault. This process involves determining which of the possible causes of faulty behavior are consistent with the observed behavior [5].

FDD tools utilize either manual or automatic methods to detect and diagnose faults. With manual methods, fault detection is performed by manually comparing the actual performance against some baseline. Manual fault diagnostic requires the knowledge of a human expert to infer the problem based on what the actual performance data show. Automated methods employ either automated comparison of actual performance data with a baseline or fault identification by recognizing patterns in the measured data. Automated diagnostics employ rule-based expert systems with decision trees to deduce the cause of the fault.

A fault is detected when the deviation of the measured performance with a baseline has exceeded a specified threshold. There are several methods to determine the comparison baseline.

- *Reference data.* Performance data from equipment manufacturers or from historical measurements can be used as the comparison baseline.
- *Modeled data.* Mathematical models based on physics and thermodynamic principals are used to generate a predicted comparison baseline for proper performance. These quantitative models use measured data as input.
- *Neural Networks.* Neural networks are software systems that consist of large interconnected networks of simple processes or tasks. The processes or tasks execute in parallel (similar to the human brain). Similar to human learning, the neural network is trained with input data and the resultant output data. Neural networks are very good with non-linear systems, where mathematical models are very difficult to derive. On the other hand, neural networks are only as good as the data that is used to train them. In FDD, a trained neural network can be used to predict output data, given a set of input data. The predicted output data is used as the comparison baseline. Neural networks fall into the category of empirical or “black box” models.”. (Note: No neural network based FDD tool was reviewed in this article)
- *Expert Systems.* Expert systems are qualitative models that use expert rules stored in a knowledge database

to infer faults from the measured input. The expert rules can be based on human expert knowledge or past operational conditions. The rules are implemented as a decision tree, or in programming language, IF-THEN-ELSE statements.

- *Fuzzy Logic.* Fuzzy logic uses fuzzy set theory to take account of uncertainties in how a HVAC system is described. A fuzzy model is a set of fuzzy rules that describe the relationship between a set of inputs and a set of outputs in qualitative terms [6]. Data are not assigned with absolute values, but rather with levels of membership to qualitative sets. For example, a temperature of 25°C may be assigned a 50% membership to the qualitative set of “warm”. The advantages of fuzzy logic are the ability to model uncertain, non-linear behavior, the simplicity of the rules, and low computational processing demands. The tradeoff is that the results are also “fuzzy,” or less precise. (Note: No fuzzy logic based FDD tool was reviewed in this article)
- *Electrical load disaggregation.* Electrical load disaggregation is not a baseline prediction method, but rather a method to deduce individual equipment power usage from one total system power usage profile. The advantage of this method is the elimination of the hardware and installation cost of submeters for the individual equipment.

Occupant Interaction and Feedback Tools

Building occupants have been an untapped source of information for

facility managers trying to improve the performance of their facilities. Human occupants are mobile and intelligent and can provide sensory feedback that cannot be matched by the most sophisticated man-made sensors. Two tools, both developed by the Center for Built Environment (CBE) of the University of California at Berkeley, utilize occupant feedback to influence building system design and operation for better performance and comfort.

The first tool, *Web-Based Occupant Satisfaction Survey*, is an environmental quality survey that is more cost-effective and faster to complete than traditional paper-based surveys. The survey has a standardized set of core questions that is used to measure satisfaction with environmental factors such as office layout, office furnishings, air quality, thermal comfort, lighting, acoustics, and building cleanliness and maintenance. Branching questions are used to capture more details where the survey revealed perceived problems. Besides the standard core set of questions, there are optional sets that deal with wayfinding, safety and security, and underfloor air distribution systems. Core survey completion time varies, ranging from 5-12 minutes. Additional optional questions increased completion time up to 20 minutes. Responses to the survey are recorded in a secured SQL (Structured Query Language) server database. Results are reported using a web-based tool.

The survey has been extensively tested and refined. It has been applied in several research scenarios that include evaluating the effectiveness of a design intervention, informing the development

of design guidelines of a new building, and benchmarking facility performance. Over 40 surveys have been completed or scheduled.

Planned enhancements of the survey tool include reporting tool improvements with more graphics, the addition of a data mining tool, support for multi-languages, and the replacement of the General Services Administration's (GSA) paper-based Facility Management Performance survey for tenant satisfaction with a web-based survey.

The second tool, *Tenant Interface for Energy and Maintenance Systems* (TIEMS), is a web-based user interface for use by building occupants (or tenants). Tenants using such a user interface will provide useful occupant feedback that should improve thermal comfort, improve performance of energy management strategies, eliminate some redundant service requests, and improve the quality of data in maintenance databases. TIEMS is being designed as a component of the GSA's GEMNet, an integrated information technology infrastructure for energy and maintenance management. TIEMS is currently undergoing field-testing. Unlike the Web-Based Occupant Satisfaction Survey tool, TIEMS is an online system that has two-way communications with a computerized maintenance management system (CMMS⁴).

⁴ A CMMS software package helps organizations manage the maintenance of equipment and facilities. For example, it can keep track of preventive maintenance schedules, service contracts, problem reports, and material

TIEMS has four key features: (1) the ability to submit and check the status of service requests, (2) the ability to see other service requests submitted during the last two hours from the same location as the current service request being submitted, (3) the ability to see a list of notices that maintenance personnel has conveyed to the tenants, and (4) the ability to check the indoor temperature.

Overall Assessment

Advanced applications are emerging because they service real needs in supporting facility operations and the maintenance group's function of providing the best environmental comfort to building occupants in the most efficient and cost effective manner.

Many of the applications would not exist without certain enabling technologies. These technologies include:

- High speed rendering of 3D graphics
- Personal Digital Assistants (PDA)
- Wireless cellular data communications
- The Internet
- Online Analytical Processing (OLAP)
- Neural Networks
- Expert Systems
- Web-based interfaces

As additional new technologies emerge, more advanced EMCIS applications will also emerge from the research

inventories. In the process, people and resources more managed more effectively.

community to eventually become standard tools for the facility/energy managers.

Potential of the EMCIS Advanced Applications

Benefits

The potential benefits of the EMCIS advanced applications are the reduction of operations and maintenance costs and the reduction of energy usage and cost without sacrificing occupant comfort. The specific benefits of each category of advanced applications can be better summarized within the context of its category.

Data Visualization Tools

- Help identify abnormal trends.
- Help identify and localize problems.
- Visual monitoring of system performance and system health.
- Reduce tedious work of raw data processing.

Portable User Interfaces

- Aid to mobile operators and facility/building managers.
- Substitute user interface when a workstation is not available.

Energy Analysis Tools

- Identify potential energy savings.
- Benchmarking.
- Use to negotiate better rates.
- Forecast loads for planning of load management strategies.
- Allocate energy use to tenants or corporate departments.
- Validate energy bills for errors.

Advanced Control Algorithms

- Optimize equipment control for better comfort, reduced energy usage, and longer equipment life.

Fault Detection and Diagnosis Tools

- Determine improper operations.
- Early detection of potential equipment failures.
- Provides better comfort with reduced maintenance and operating costs.

Occupant Interaction and Feedback Tools

- Occupant feedback to designers helps future designs.
- Used for benchmarking to identify under-performing buildings.
- Feedback to building operations helps to improve comfort, occupant satisfaction, and lower operations costs.

Limitations

As with any tool, the potential benefits of the EMCIS advanced application tools can only be realized if the tools are utilized properly. That means the proper operator training is very important.

Since these tools are in many cases additional to the cost of the EMCIS, one must determine whether the cost savings justifies the additional cost. In the cases where the tools are still being perfected by the researchers, one questions whether the research results can be applied to real world operating conditions?

Cost Effectiveness

It is beyond the scope of this article to analyze the cost effectiveness of EMCIS advanced applications. In many cases,

the applications are still in the research stage and any cost effectiveness analysis is pre-mature. In other cases, one can compare C&M cost before and after the advanced application tool is deployed as a means to determine cost effectiveness. And finally in some cases such as fault detection and diagnosis tools, a single use of the tool may justify the cost of the tool if the tool discovered a major fault and the correction of the fault resulted in a large savings in O&M cost.

Summary and Conclusions

The advanced EMCIS application products reviewed in this article cover a wide spectrum of functionality. Many, if not all, utilize the latest technologies. As even newer technologies emerge, expect more advanced applications with new innovations will also emerge.

The standard functions of EMCIS do not serve all the needs of building, facilities, and energy managers. The advanced applications provide the tools for these professionals to operate their facilities with better comfort, higher or better performance, and at a lower cost.

Poor system commissioning and faulty equipment operations are common problems today. Re-commissioning is a costly process and identifying faulty equipment operations is an art form. As FDD tools emerge from research and mature, the FDD tools will likely have a significant and large impact.

Appendix A. Acronyms and Definitions

Many acronyms used in this article can be found in the Glossary sections of References [1], [2], and [3]. Additional definitions are included here.

ASP	Applications service provider
CBE	Center for Built Environment, University of California, Berkeley
CMMS	Computerized maintenance management system
FDD	Fault detection and diagnosis
GSA	General Services Administration
OLAP	Online analytical processing
P	Proportional
PDA	Personal digital assistant
PI	Proportional plus integral
PID	Proportional plus integral plus derivative
SQL	Structured Query Language
TIEMS	Tenant Interface for Energy and Maintenance Systems

Appendix B. Applications tools products and features

The following tables list products and their features for each of the applications categories studied. Each table is customized to show the features of significance to the category. A detailed explanation of each feature is included at below each table.

	Products (vendor)
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Energy Analysis	Active Energy Management (Engage Networks)	Atrium (Honeywell)	EEM Suite (Silicon Energy)	Electric Eye (Electric Eye)	Energy Commander / Energy Analyzer (TruePricing)	Enerwise Energy Management (Enerwise Global Technologies)	EnterpriseOne (Circadian Information Systems)	ExcelSyus (Excel Energy)	FX-TEM (Johnson Controls)	InfoCenter Suite / Utility Cost Manager (Siemens)	Vykon / Vykon Energy Suite (Tridium)
General Features											
Applications Service Provider (ASP)		•			•	•					
Web Interface	•	•	•	•	•	•			•		•
Data Collection Gateway Hardware	•			•	•			•			•
Energy Analysis											
Benchmarking			•								
Multi-site Comparison	•		•				•				
Aggregation	•	•	•					•	•		•
Advanced Data Mining (OLAP)											
Load Analysis											
Load Management	•	•	•			•					•
Load Profiles			•	•		•	•	•	•	•	•
Load Duration	•		•								
Billing Analysis											
Rate Engine	•	•	•			•	•		•		
Energy Invoicing	•	•	•			•	•			•	
Bill Verification		•	•				•		•		
Forecasting											
Forecasting		•	•								
Weather Link	•	•	•			•	•				
Reporting											

	Products (vendor)										
	Active Energy Management (Engage Networks)	Atrium (Honeywell)	EEM Suite (Silicon Energy)	Electric Eye (Electric Eye)	Energy Commander / Energy Analyzer (TruePricing)	Enerwise Energy Management (Enerwise Global Technologies)	EnterpriseOne (Circadian Information Systems)	ExcelSyus (Excel Energy)	FX-TEM (Johnson Controls)	InfoCenter Suite / Utility Cost Manager (Siemens)	Vykon / Vykon Energy Suite (Tridium)
Energy Analysis											
Energy Reports	•	•	•		•	•	•		•	•	•
Exception Reports						•				•	•
Operations Support											
Real-time monitoring			•	•			•				•
Alarming	•		•		•	•				•	•
Remote Control		•	•		•			•			•
Distributed Energy Resource Control	•	•	•			•					

General Features

Applications Service Provider (ASP). An Applications Service Provider is a company that provides the use of applications software as a service to end-users. The ASP will host the software on its servers and access to the applications is via the Internet. Since the applications are not located on site, collected data is also transmitted to the ASP servers over the Internet.

Web Interface. The user interface for the application is a standard Web browser. With a Web Interface, no user interface software is required for workstations accessing the energy analysis application. The use of a Web Interface reduces the cost of software maintenance and upgrade.

Data Collection Gateway Hardware. Some vendors provide a hardware gateway device to collect data from the control system. These gateway devices perform network bridge functions, protocol translations, and act as the Internet interface for those applications that are not located on site.

Energy Analysis

Benchmarking. To benchmark different buildings or sites, energy data can be normalized by square footage, number of occupants, outside air temperature, cooling/heating degree days, etc. and categorized by geographical region, building type, business type, etc.

Multi-site Comparison. This feature usually compares whole building energy consumption of each building in a bar chart. The feature is useful for multi-facility operators that need to target sites for energy efficiency retrofit.

Aggregation. Loads from several sources are aggregated (combined) into a total value. The aggregated data can then be analyzed like any

other data point (for example load profiles). Using aggregated loads can save the cost of installing separate meters to measure total or subtotal loads. It also allows the flexibility to aggregate different sources and at different times if such analysis is required.

Advanced Data Mining (OLAP). Large amounts of data can be analyzed using custom reports that are designed interactively. Data can be “sliced, diced, and drilled down” to extract the information from different perspectives. The advanced data mining capabilities are provided by Online Analytical Processing (OLAP) technology.

Load Analysis

Load Management. This feature covers tools used to manage peak loads. These tools include tools for curtailment contract management, notification with pricing, bid submittal, event monitoring, and baseline comparison. Also included are tools for defining and activating curtailment and load shed strategies.

Load Profiles. Load profiles are trend plots of load over a period of time. Normally, the period is a 24-hour period. This common graph provides easy verification of operating schedules, identifies peak hours, and can also be used to develop baseline load profiles.

Load Duration. The load duration curve is a histogram that indicates the percentage of time the load was at a particular value. The graph has percentage as the x-axis and the load (kW) as the y-axis. If the curve spikes up at the low percentage area, it indicated that there is high peak demand at infrequent times.

Billing Analysis

Rate Engine. Past interval meter data can be passed to the rate engine software to compute a bill. Different rates can be used to determine the optimal one. The analysis aids in forecasting future energy costs and determining the lowest cost energy provider based on the energy usage pattern of the facility.

Energy Invoicing. Interval data from submeters are used to generate energy invoices for facility tenants or for energy cost allocation to corporate departments.

Bill Verification. Interval meter data and energy rate data can be used to compute a monthly energy cost for verification against the actual utility bill.

Forecasting

Forecasting. Forecasting tools use a combination of proprietary algorithms, historical load data and weather statistics, and temperature forecasts to generate predicted 24- and 48-hour energy usage. The forecast can be used to determine whether strategies should be deployed to avert peak demand charges.

Weather Link. Weather data is usually retrieved either from a commercial weather service or from one of the government-operated weather bureaus. Weather data can be used just for informational purposes, but in most cases, the weather data is used for more accurate forecasting.

Reporting

Energy Reports. Energy reports include both textual and graphical reports. Common reports include energy usage summary (by site,

building, etc), daily load profiles, aggregation reports, energy use ranking (vertical bar chart), and relative contribution (pie chart).

Exception Reports. Exception reports are generated for data that do not fall into a user-defined range during a specified time period. These reports can be used to identify problems.

Operations support

Real-time monitoring. Data is collected and displayed in real time (or near real time).

Alarming. The alarming feature includes a set of tools that perform out of range detection, alarm notification (email, pager, fax, PDA, etc), and alarm management (acknowledgements, resolution, logs, and audit trails).

Remote Control. Most applications perform only data collecting and monitoring functions. However, some applications permit remote control functions such as changing setpoint values and turning equipment on and off.

Distributed Energy Resource Control. Distributed energy resources such as internal combustion generators, fuel cells, micro-turbines, photovoltaic panels and wind power generators can be remotely controlled in a variety of ways. Control can be range from simple on/off control, to pre-defined schedules, to automatic triggering by events such as alarms, demand, temperature, and price thresholds, to sophisticated algorithms that factors in marginal cost of generation, marginal cost of grid energy, and forecasted load.

Data Visualization	Active Energy Management (Engage Networks)	EEM Suite (Silicon Energy)	Electric Eye (Electric Eye)	EnterpriseOne (Circadian Information Systems)	Metasys (Johnson Controls)
Standard Data Visualization Tools					
Graphical Equipment Monitoring		•	•	•	•
Trend Plots	•	•	•	•	•
Advanced Data Visualization Tools					
Multi-Point/Variable Overlay Trends	•	•	•	•	•
Multi-Day Overlay Trends	•	•	•	•	
Calendar Profiles	•			•	
3D Surface Profiles	•	•	•		
X-Y Scatter		•	•	•	
Performance Monitoring Tools					
Analog Profile					•
Comfort Chart					•
Color Spectrum					•
River of Time					•
Starfield Display					•
System Analysis Tool					•

Standard Data Visualization Tools

Graphical Equipment Monitoring. Instead of showing real-time equipment data in a tabular form, graphical equipment monitoring displays show the real-time data on a graphical representation of the equipment. One can even use a digital photograph of the equipment. The idea of graphical equipment monitoring is to give the operator a more intuitive sense of how the equipment is operating. Also, if there are any alarms, the alarms on the display can immediately point the problem to the operator. However, some operators find the graphical displays unnecessary and prefer lists and tables instead.

Trend Plots. A trend plot is a time series plot of a data point. Viewing trend data graphically is preferred over the traditional method of viewing a textual log. Graphical views allow easier identification of irregularities as well as abnormal trends.

Advanced Data Visualization Tools

Multi-Point/Variable Overlay Trends. Multiple variables or points are displayed on the same plot and with the same time period. In a multi-point/variable trend plot, one can see relationships between points/variables as time progresses.

Multi-Day Overlay Trends. Multiple days of data from the same point are displayed on the same plot (normally in a 24-hour period). Any trends that occur in a similar fashion from day-to-day, or only on weekdays or weekends can be easily identified.

Calendar Profiles. This plot is a continuous plot of trend data for a one-month period. The trend plot is segregated by boxes; each box representing a single day and the boxes organized like the days of the month on a calendar. The calendar profile can be used to identify any abnormal days, differences between weeks of the month, and differences between weekdays and weekends.

3D Surface Profiles. A variation of a multi-day trend plot but instead of plotting the days all on a 2D plane, the days are plotted on a third axes. The resultant plot is a 3D surface plot. For example, a 3D surface plot of system energy use will show valleys of low energy use and peaks of high energy use.

XY Scatter Plots. Scatter plots or XY plots graph one variable on the x-axis against another variable on the y-axis. Each point on the plot represents the values for both variables at an instance in time. Scatter plots normally contain points from a large number of samples. One can easily see the correlation between the two variables as well as potential abnormal conditions when a sample point lies far from all other samples. The ability to properly filter the data set for transient and spurious data is important to being able to see trends and spot the abnormalities.

Performance Monitoring Tools

Several advanced data visualization tools, classified as performance monitoring tools, use "abstraction" and "metaphor" visualization techniques to view several inter-related data at the same time. These advanced tools allow easy identification of system performance and can help identify impending equipment faults.

Analog Profile. The Analog Profile display consists of two horizontal bars. The left bar shows how much higher or lower the data point is from its setpoint. A small rectangle gives an indication of the rate of change for the data point. Several data points can be viewed by stacking the horizontal bars vertically. One can easily see normal conditions such as data point values over setpoints, but negative rate of changes. Abnormal conditions would be a positive rate of change. On the right of

each bar is displayed another bar that represent the relative flow (0-100%) of a data point that's related to the first.

Comfort Chart. The Comfort Chart shows temperature on the x-axis and humidity on the y-axis. A visual pattern on the chart uses the ANSI-ASHRAE 55-1992 comfort standard to highlight the temperature and humidity range where 80% of people should feel comfortable. Temperature and humidity sensor values for rooms and zones of interest are plotted on the display in real time. Where the data points lie and watching the movement of the points over time help in detecting possible heating and cooling problems that will lead to occupant discomfort.

Color Spectrum. In Color Spectrum, colors are assigned to particular historical values of a data point. The display shows daily, weekly, or monthly views of the data point as horizontal bars. The colors will bring out any daily/weekly/monthly patterns that can be identified for further investigation.

River of Time. River of Time is a dynamic display that uses a 24-hour bar to represent 12 hours of past data on the left, 12 hours of future scheduled state on the right and the current state in exactly the middle. As time passes, the display flows from right to the left. For example, the past 12 hours of a fan status can be displayed. Colors on the bar can indicate on/off/alarm status. The future 12-hour scheduled on/off state (setpoint) of the fan is shown on the right. Several parameters can be

viewed with the same display. With this display one can quickly see what the state of various components in the system had been in the past 12 hours, and what the future states will be in the next 12 hours.

Starfield. The Starfield display consists of star clusters on a black background, with each cluster representing an area of interest in a building. For example, the central star in the cluster can represent a fan. The surrounding stars in the cluster can represent the zones controlled by the fan. The size and color of the central star show the fan's on/off status and normal/alarm state. The color of the surrounding stars show whether the zones are warm, cool, or normal, relative to the zone setpoints. The distance of the surrounding stars from the central star indicates how far the zone is away from the setpoint. By recognizing the star cluster pattern and colors, an operator can quickly identify problems.

System Analysis Tool. The System Analysis display can display data from many different types of points with different units and varying ranges. Each point value is represented as a bar and scaled individually. The rate of change is also displayed as well as little arrows to indicate the direction the point value is going. There are also minimum and maximum indicators that track the historical minimum and maximum values the point had been. The System Analysis tool enables operators to quickly see the performance of the entire system in a single display.

Portable User Interfaces	PocketControls (Abraxas Energy)	Sigma Compact Edition (Invensys Climate Controls – UK)
Operating System		
Windows CE		•
Pocket PC	•	
Communications		
Wireless	•	
Ethernet		•
Serial		•
Features		
Pre-configured Server	•	
View/Acknowledge Alarms	•	•
View Point Values	•	•
Change Setpoints	•	•
Trend Logs	•	
Graphical Trending	•	•
Load Profiles	•	
Reports	•	

Operating System

Windows CE. Windows CE is an embedded version of the Microsoft Windows operating system (OS) used mainly in PDA (Personal Digital Assistant) or handheld type PC's. Windows CE has been superseded by Microsoft's new embedded Windows OS, Pocket PC.

Pocket PC. This is the current Microsoft embedded Windows OS for PDA's.

Communications

Wireless. Wireless communications is provided by cellular modem technology.

Ethernet. Can connect directly to the Ethernet equipment bus.

Serial. Can connect directly to a local field panel using a serial cable.

Features

Pre-configured Server. A special server with pre-configured software is used to interface the BCS to the wireless service provider. The server communicates two-way with the BCS and wireless service.

Pre-configured Server. A special server with pre-configured software is used to interface the BCS to the wireless service provider. The server communicates two-way with the BCS and wireless service.

View/Acknowledge Alarms. Alarms can be viewed and acknowledged on the portable user interface.

View Point Values. View the current values of data points.

Change Setpoints. Setpoints can be changed from the portable user interface.

Trend Logs. Time series data (trend logs) can be viewed as tables.

Graphical Trending. Trend log data can be viewed graphically on the portable user interface.

Load Profiles. Trend plots of building KW and KWh usage.

Reports. The PDA or the server has a set of pre-configured reports.

Advanced Control Algorithms	Adaptive Capacity Control (York)	Enhanced Adaptive Control (Trane)	Finite State Machine (Johnson Controls / NIST)	HVAC-Pro (PRAC) (Johnson Controls)	Neural Networks (Colorado State University)	Neural Networks (U. of Colorado & U. of Nebraska)	P-Adaptive Control (Johnson Controls)	PRAC (Johnson Controls)
Product Status								
Research			•		•	•		
Commercial	•	•		•			•	•
Applied Method								
Finite State Machine			•					
Neural Network					•	•		
Loop Tuning				•				
Pattern Recognition				•				•
Self-Adjusting Deadband							•	
Adaptive VSD Speed Control	•	•						
Adaptive Control Parameters				•			•	•
Equipment Application								
VAV				•			•	•
AHU			•	•				
Unit Controller				•				
Chiller	•	•				•		
Heating Coil					•			

Product Status

Some of the advanced control algorithms are still at the research level. Others are available commercially and already have an installed base.

Applied Method

Finite State Machine. Finite state machine is a new logic for program control sequence. The logic defines specific states, or modes of operation, for the process (such as heating, cooling, fan on, fan off). Each state also contains specific control logic. Finite state machine control sequence logic eliminates some of the common problems such as simultaneous heating and cooling and rapid cycling between heating and cooling modes. Finite state machine logic is easier to define, illustrate, and program, compared to traditional control logic.

Neural Network. Neural networks distribute computational tasks onto many identical simple units that are highly interconnected and can work in parallel (some resemblance to the human brain). Neural networks deal well with arbitrary nonlinear problems with numerous simultaneous constraints and exhibit the ability to “learn.” Neural networks are ideal for systems rich with data, but poor with theory, as well as systems that are non-stationary, nonlinear, and dynamic. In order for neural

networks to operate, they must be “trained” with input data and expected output data.

Pattern Recognition. The control algorithm monitors specific input, output, and setpoint data for specific patterns. With each recognized pattern, the algorithm will issue the associated control directives.

Self-Adjusting Deadband. With this control algorithm, the deadband is dynamically adjusted based on the value of measured data. The result is a very responsive, but also a very stable control system.

Adaptive VSD Speed Control. Controllers on variable speed drives for chillers learn and remember the optimal speeds for variable-load and water-temperature combinations. The controllers instruct the drives to initiate the proper speed and pre-rotation vane position for maximum energy savings.

Adaptive Control Parameters. Control loop tuning parameters (proportional band and integral time) are continuously adjusted for optimal closed loop control.

Equipment Application

This section of the table lists the equipment application for each of the advanced control algorithms.

Fault Detection and Diagnosis	ACRx (Hand Tool / Service Tool) (Field Diagnostic Services / Honeywell)	APAR/VPACC (NIST)	Enforma (Architectural Energy Corp.)	AHU Diagnostics Toolkit (Center for Built Environment)	FDD for Rooftop AC (Purdue University)	IMDS (LENL)	NILM (MIT)	PACRAT (Facility Dynamics)	Universal Translator (PG&E / PEC)	MIFDD (PG&E)	WBD / OAE (PNNL)
Product Status											
Research		•		•	•	•	•		•	•	•
Commercial	•		•					•			
Data Collection Method											
Online	•				•	•	•				•
Batch		•	•	•				•	•	•	
Detection Method											
Automated	•	•			•		•	•		•	•
Partial Automated									•		
Manual			•	•		•					
Diagnosis Method											
Automated	•	•			•			•			•
Partial Automated							•				
Manual			•	•		•			•	•	
Applied Method											
Manual Data Visualization			•	•		•	•		•		
Expert System – Rule-Based	•	•			•			•			•
Compare w/Reference and Perf. Data			•	•					•		
Compare w/Modeled Baselines								•		•	•
Electrical Load Disaggregation							•				

Fault Detection and Diagnosis	ACRx (Hand Tool / Service Tool) (Field Diagnostic Services / Honeywell)	APAR/VPACC (NIST)	Enforma (Architectural Energy Corp.)	AHU Diagnostics Toolkit (Center for Built Environment)	FDD for Rooftop AC (Purdue University)	IMDS (LBNL)	NILM (MIT)	PACRAT (Facility Dynamics)	Universal Translator (PG&E / PEC)	MIFDD (PG&E)	WBD / OAE (PNNL)
Equipment Application											
Whole Building						•		•			•
Rooftop AC	•				•						
AHU (E-Economizer)		•	•	•				•	E		•
Cooling Towers			•			•					
Chillers			•					•			
Heating Plants			•								
Zone Distribution Systems (V-VAV)		V	•					•		V	
Hydronics Systems								•			
Fans and Pumps				•		•					
Elec. Equip. Cycling/Schedule Faults							•				

Product Status

Fault detection and diagnosis tools are emerging applications in building operations and maintenance. Many are still in R&D with functional prototypes at various universities and research laboratories across the country. A few are commercialized and available for purchase from private companies.

Data Collection Method

Data used by the fault detection and diagnosis applications can be provided either on a batch basis (electronic files containing the historical data) or on an online basis. In the online case, the application is either resident on the equipment or has communications access to the equipment.

Detection/Diagnosis Method

The detection and diagnosis of faults can be by manual or automatic means. Manual detection uses visual comparison of actual data against predefined data, reference data, statistical data, or historical baseline. Automatic detection either uses expert rules and decision trees to determine the presence of a fault or compares actual data against modeled data to determine the deviation that indicates a fault.

Manual diagnosis requires a human expert to analyze the state of the equipment at the time of the fault and diagnose the cause of the fault. Automatic diagnosis uses expert rules and decision trees to determine the cause of the fault.

Applied Method

Manual Data Visualization. This is the manual process of detecting faults. The process requires a human expert that can recognize abnormalities by viewing data logs either textually or graphically.

Expert System – Rule-Based. Equipment data are compared to a series of rules based on expert human knowledge of the operation of the equipment. If the equipment data point fails all rules for proper operation or fits a rule for improper operation, a fault is signaled.

Compare with Reference and Performance Data. Comparisons are made between actual data plots with pre-defined reference plots or from performance plots provided by the equipment manufacturer. Excessive deviations from the baseline signal potential incorrect equipment operation

Compare with Modeled Baselines. Actual data plots are compared to baselines calculated from models. Excessive deviations from the baseline signal potential incorrect equipment operation.

Electrical Load Disaggregation. The electrical load profile is monitored for patterns that signal equipment are being turned on or off. The equipment on-off profile can be compared with the equipment schedule to determine scheduling faults or excessive cycling faults.

Equipment Application

The diagnostic scope for the tools can be at the whole building, or high-level, top-down, approach. At this level, parameters such as energy consumption for the whole building are used to reason about causes for equipment-level problems. Alternatively, in a low-level, bottom-up approach, low-level parameters are used to detect equipment problems directly

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